Annual Report for
"A Framework and Tools for Organizational Simulation"
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Summary

This report documents the progress and accomplishments made in the first year of this project with respect to the tasks specified for year one, and it also describes plans to start the tasks specified for the second year of the project. In general, the project has proceeded as planned, with planned targets being met.

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14. ABSTRACT

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Project Background

The goal of this project is to specify a framework and develop tools for organizational simulation (Rouse & Boff, 2005). Computer simulation is a relatively mature field in terms of modeling such phenomena as processes. It is less mature at modeling such phenomena as human and organizational behavior. This project seeks to advance the state-of-the-art with respect to simulation modeling of organizations through specification of a modeling framework and associated tools for model development. This framework is based largely on the integration of three existing simulation modeling paradigms – agent-based, system dynamics and discrete-event – into this modeling framework. Each of these paradigms contributes a subset of organizational phenomena that it can model. System dynamics provides methods to model continuous flow systems, while discrete-event simulation provides methods to model transaction-based process systems. Agent-based simulation is a less mature technology that can be used to model human behavior, but is not well-developed in this regard. This project uses concepts from the emerging field of interactive drama to provide realistic human behavior modeling capability. It also uses the interactive drama concept of a drama manager to guide the playing out of organizational stories to explore different scenarios.

Project Tasks and Deliverables Status for Year 1

1. Task. Define standard terminology and reference model for organizations and organizational components (world model elements, character model elements, organizational story elements).

   Results. A reference model is a conceptual model of a class of systems for purpose of describing important system elements and their inter-relations. In the context of this project, the "system" being simulated is an organization. Reference models have been proposed as a means to facilitate development of modeling tools for the particular class of systems being studied. The strengths provided by a reference model include the following:
   - It should provide a common understanding of class of systems to be modeled (e.g., a standard terminology).
   - It should help ensure completeness of modeling tools.
   - It should improve reusability of modeling abstractions.
   - It should aid in modeling complex systems elements.

   We have specified a generic organizational reference model, documented in a technical report (Bodner, 2009). This organizational reference model provides a basis for modeling libraries for organizational simulation software. The reference model is organized along the following lines:
   - Organizational architecture. These abstractions address important organizational components, such as organizational units, people and roles, and the different types of formal relationships between them.
   - People. These abstractions support modeling of attributes (e.g., skills and roles) and behavior (e.g., decision-making, communication, execution of tasks) of people.

- Processes. These abstractions address tasks, precedence relationships between tasks, skill requirements for tasks and task durations, as well as the business artifacts that are processed.
- Organizational artifacts. Organizations typically create and use a variety of artifacts to aid in process execution and performance tracking. These abstractions address those artifacts and include the following types of elements: offerings (i.e., the set of products or services offered by the organization), chart of accounts, budget, organizational skill-set (e.g., the set of skills needed to support mission), and decision support systems.
- Social and organizational networks. Organizations are characterized by informal relationships between organizational units and/or individuals. Similar to the formal organizational architecture, these informal relationships consist of organizational units, people, and roles. Relationships include such factors as communication level, trust, skill-set affinity or location proximity. Roles include gatekeeper and hub.
- Eco-systems. Organizations exist in the context of an eco-system. This eco-system has exogenous effects on the organization. The eco-system may contain other organizations directly modeled (e.g., competitors, collaborators, enemies), and it may also contain effects from other organizations that are modeled indirectly (e.g., threats or the economy).
- Outcomes and value. Outcomes and value relate to the mission of an organization. Value is how outcomes are measured in this sense. Value may be monetary (e.g., profit, revenue or cost), or it may be non-monetary (service level, prevention of threats, etc.).

Deliverable status: Completed.

2. Task. Select human system integration (HSI) case study featuring a world model, characters and organizational stories for use in prototyping the organizational simulation tools.

   Results. The HSI case study selected for this project focuses on the military acquisition enterprise. In particular, it focuses on the acquisition of the Predator unmanned aerial system via an Advanced Concept Technology Demonstration (ACTD) process during 1994-1996. This acquisition has been documented extensively, and thus information is available for model development (Thirtle et al., 1997). In acquisition, there are two types of human-system integration problems. The first concerns when and how to make investments into HSI during system development. The second concerns designing the acquisition enterprise (processes, incentives, information availability, etc.) so that human decision-making is effective within the enterprise, where the enterprise is considered as a system. Given that this project addresses organizational simulation, the primary current focus is on the second type of HSI issues.

   The goal behind the case study is to provide a world model, characters and organizational stories useful in helping prototype organizational simulation models. In achieving this goal, there are two major requirements that must be met.
   - The case study must exhibit sufficient complexity that the deliverable will be useful.
   - It must also exhibit sufficient generalizability to allow future applications to be further developed from the platform of the accomplished work.

Certainly, the military acquisition enterprise is complex. The ACTD, in fact, is a simplified version of a full-scale acquisition process. Still, it exhibits sufficient complexity for use as a case study due to multiple, interacting stakeholders who determine outcomes. The world model consists of uncertainties, processes, process flows, and external world effects. Characters make decisions involving funding, lead service selection and the transition of the program to the formal acquisition enterprise. There are numerous potential organizational stories (e.g., risk mitigation, cost management, process design, and portfolio management). We anticipate that this case study will generalize to other types of military organizations, such as other programs (e.g., acquisition of other systems, sustainment of systems), military bases or coalitions, as well as commercial organizations (e.g., new product development, logistics, extended enterprises).

This case study has interesting organizational effects that will allow study of the following types of issues – the determination of military utility of a system, interaction between that determination and the timing of lead service selection, the choice of development manager and operational manager, and the stability of funding during the program.

Deliverable status: Completed.

3. Task. Compile full listing of discrete-event, agent-based and system dynamics simulation packages to be considered; evaluate and select at least one from each category to be used.

   Results. Evidently, there is no officially sanctioned simulation modeling software used by the Department of Defense or the Air Force. Hence, we developed a number of criteria by which to judge available simulation packages and made a selection based on those criteria. The criteria are as follows.

   Modeling paradigms supported:
   - Whether the software supports discrete-event modeling.
   - Whether the software supports system dynamics modeling.
   - Whether the software supports agent-based modeling.
   - The degree to which the software supports human and organizational modeling.

   Model building characteristics:
   - The degree to which the software can be customized so that organizational simulation libraries can be developed.
   - Whether the software has a graphical user interface development environment (IDE).
   - What programming languages are supported by the software for customization that may be needed for organizational library integration.
   - To what extent is the software interoperable so that it can be integrated with other software.

   Model usage characteristics:
   - Whether the software has an animation graphical user interface (GUI).
   - Whether the software supports statistical analysis of simulation results.

- Whether the software supports database integration, so that data elements can be stored in a database to facilitate data management.

General software characteristics:

- Whether the software is currently supported.
  - By a company (for commercial software, which typically has maintenance and technical support).
  - By a community (for open-source software, which usually has support via mailing lists and website postings).
- The cost of the software.

We reviewed nineteen simulation software packages and chose AnyLogic, a commercially available simulation packages that integrates agent-based, discrete-event and systems dynamics simulation. The full list of packages is available in Appendix A. It should be noted that none of the alternatives supported the concept of organizational simulation as envisioned in this project, although MicroSaint Sharp/IPME addresses human performance from a human factors perspective.

AnyLogic (www.xjtek.com) is more attractive than the other alternatives due to a combination of features, including its being the only one to integrate all three simulation paradigms. Other features include the following:

- Being Java-extensible, which allows straightforward development and integration of add-on libraries to support organizational modeling.
- Graphical IDE, which facilitates library and model development.
- Basic modeling capabilities, similar to other packages that support agent-based, discrete-event or system dynamics modeling.
- Post-simulation analysis tools, which allow statistical analysis of model execution results.
- Database integration capability, which allows data to be stored in and queried from a database, enabling more effective and efficient management of model data.
- Academic license, which provides a lower cost solution.

Deliverable status: Completed.

4. Task. Design/implement first generation libraries of component organizational models, and modeling building blocks, suitable for composing an overall organizational model (world model and organizational stories).

   Results. In general for tasks 4-6, the class libraries are being implemented in Java so that they can be integrated into the AnyLogic platform. Many are sub-classed from the existing AnyLogic object model, while others are designed separately. The implemented classes are then compiled into libraries and integrated into AnyLogic. In general, the libraries map to elements of the reference model. It was discovered that direct export of the libraries is not enabled for the academic license of AnyLogic used in the project. However, export can be accomplished using the AnyLogic project construct, which is sufficient for functionality of the libraries. This issue will be investigated further in year two of the project for improved usability.

Specifically for task 4, organizational component classes are organized into the following libraries.

- Organizational elements library. This library addresses the architecture and constituent elements of the organization, as well as its informal social network structure. It provides the following:
  - Organizational actors (organizational units and individuals) based on sub-classing from the agent framework, which gives them state transition capability and a framework for implementing behaviors.
  - Organizational relationships include actor-to-actor relationships from the formal organizational architecture (reporting, collaboration and goods/service provision), actor-to-actor relationships from the social network (trust, communication), and actor-to-role relationships (assignment of actors to roles specified in task 5).
- Process library. This library is based on the existing AnyLogic discrete-event model, which is relatively mature. Thus, it provides specialized objects and behavior for organizational processes, including queue-ordering according to some criterion, specialized process flow artifact classes (system concepts, system prototypes, funds, etc.), and capability for agents to traverse processes via paradigm integration.
- Organizational artifact library. The artifacts in the first generation library include offerings, budgets and organizational skill-sets. These are designed based on stand-alone Java classes.
- Outcomes and value library. The first generation outcomes and value library includes mostly financial metrics – cost, revenue, profit and utility. These are designed based on stand-alone Java classes.

Deliverable status: Completed.

5. Task. Design/implement first generation libraries of role models that relate organizational roles to human decision making, problem solving, communication, etc. (character models in relation to world models and organizational stories).

   Results. The representation for role models is based on a Java class framework. Essentially, it provides content for organizational structure in terms of the different roles that characters might play in an organizational simulation. The focus for the first-generation set of role models is on formal organizational roles, rather than informal roles.

   The specific roles are supervisor, supervisee, operational manager and development manager. Associated with each role is a specific set of behaviors that are implemented as part of the behavior modeling in task 6 (human decision making, problem solving and communication).

   Deliverable status: Completed.

6. Task. Design/implement first generation libraries of behavioral and social phenomena that provide mappings from relevant theory and data to representations within role models (character model details and social networks).

Results. These classes provide the behavior of the organizational actors (from task 4). In particular, character models have been designed using agent-based representations for individuals and organizational units. We have integrated a character programming framework into the agent-based representation provided by AnyLogic. The particular language used is ABL (A Behavior Language), which provides a framework for realistic, theory-based agent behavior representations (Mateas & Stern, 2004). ABL provides the basis for development of a behavior library that includes goals, behaviors, working memories, an active behavior tree for currently executing behaviors, and joint behaviors involving multiple characters. In the first generation library, the focus is on individual behaviors; joint behaviors will be addressed in year two. Social phenomena can be represented using the individual behavior construct, but the joint behaviors will provide a more robust method of doing this (including teaming behaviors). It should be noted that ABL provides hooks for natural language processing and character animation that are not used in the current project, but may be used in future extensions. AnyLogic and ABL are integrated via a specialized Java class that provides the interface between the AnyLogic process and the ABL process.

The behavior library focuses on decision-making, task execution and reaction to incentives and information. In particular, the following are included:

- Determine utility
- Assess risk
- Select from multiple alternatives
- Start execution of a pre-defined process (e.g., service or goods provision)
- Follow a process
- Communicate with other actors
- Provide information to other actors
- Provide goods/services to other actors

Deliverable status: Completed.

7. Task. Perform initial verification and validation on all implementations.

   Results. Initial verification and validation has been performed by expert review using personnel from the Tennenbaum Institute to review the class library. This has been done via comparison of the class library to a conceptual model described in Rouse et al. (2009). The class library and this conceptual model were developed independently. Additionally, the abstractions from the library have been reviewed against the case study to determine the completeness of the library. In both cases, there were no shortcomings indicated with the class library other than extensions needed for a more complete set of abstractions. These are planned for the second year (task one).

   Deliverable status: Completed.

8. Task. Define requirements/functionality and design organizational story drama manager.

Results. A drama manager is a concept from the field of interactive drama, which is an emerging field of research within gaming and artificial intelligence. An interactive drama is similar to a game, except that there is not game-play in the sense of scoring, but rather role-play in the sense of a story that plays out. The player interacts with a computational model that represents the drama (e.g., plot and characters), as it unfolds over time.

Similarly, a simulation model unfolds over time. Traditionally, simulation models execute as a series of events and associated state changes that, taken together, simulate the behavior over time of a system (or organization in the context of this project). In agent-based simulations, state changes as the result of interacting agent objects. In discrete-event simulations, state changes as the result of event calendar processing or transaction processing. In system dynamics simulations, state changes as the result of differential equation processing. In an interactive drama, the story unfolds over time as a sequence of events, some of which are chosen by a player who interacts with and is part of the drama. The author of the drama has a certain intent with respect to the quality of the drama, in terms of realism or dramatic effect. Thus, researchers in interactive drama have created the concept of a drama manager to guide the story line in accordance with this intent. The goal here is to use this concept provide a better exploratory functionality for simulations than that which exists today.

We have consulted with researchers in the field of interactive drama to translate their concept for a drama manager into one suitable for organizational simulation. The requirements that we have developed for the organizational simulation drama manager are as follows:

- Guide an organizational story according to some evaluation function:
  - Current focus on pure simulation.
  - Future enhancement to simple user-in-the-loop simulation (operating via breakpoints).
- Support framing of scenarios.
- Support exploration of organizational story space.

From a user's point of view, the functionality that we have specified for the drama manager is the following:

- User co-develops a simulation model and a drama model:
  - These need to be consistent with one another.
  - Drama model is a subset of important simulation events.
- The drama model is linked to elements of the simulation model for purposes of execution control.
- A drama manager agent controls navigation through the drama model (and hence the simulation):
  - Modeler specifies an evaluation function.
  - Drama manager has (limited) search capability to explore the drama model to find "good" directions.

The drama manager is designed as a sub-class of the AnyLogic Agent class. The design of the drama manager includes the following elements:

- Evaluation function. Our initial focus is organizational risk, which is characterized by a type of bad outcome and the probability that the type of outcome will occur. The function evaluates quantitatively to the product of the outcome and the probability. In terms of the acquisition case study, one type of risk is a cost overrun. The evaluation of risk would then be the product of the estimated overrun and the probability of the overrun. This could be expressed as an estimated value over a number of different possible overrun outcomes.
- Search capability. The drama manager has methods to search the organizational story space (i.e., the set of plot points) to determine the best path through the story. It can be set to minimize the evaluation function (i.e., find a low risk path) or maximize it (i.e., find a high risk path). This allows the analyst to determine which scenarios result in high versus low risk. The current design uses a branch-and-bound search so that an exhaustive search is not required (due to potentially high computation time required for an exhaustive search).
- Plot point representation. Plot points are important events in the organizational story that are used by the drama manager to navigate through the story, and they comprise the drama model. Plot points are related to one another via a directed, acyclic graph that represents precedence relationships between events. Plot points are mapped to objects in the simulation reflecting their relationship to simulation events.
- Plot point manipulation (trigger, disable, delay, etc.). The drama manager has actions that it uses to guide the organizational story. It has methods, for instance, that may disable plot points from occurring, or may trigger a plot point. It may also operate probabilistically by changing the probability that certain plot points will occur.

Current work is moving beyond the design phase to address the application of this general purpose design to the specific case study involving acquisition. The particular focus is on the selection of the lead service for the Predator. In the case study, this selection was made late and also was done using subjective criteria. The lateness resulted in the lead service's input not being factored into the system design, causing extra work (and cost) to be required.

Deliverable status: Completed.

9. Task. Present findings at a technical conference.

   Results. Findings to date were presented at the 2009 Industrial Engineering Research Conference, held on June 2, 2009, in Miami. The IERC is the premier research conference sponsored by the Institute of Industrial Engineers. The title of the presentation was "Organizational Simulation to Support Design of Military System Acquisition Processes." The abstract for the presentation is included in Appendix B.

   Deliverable status: Completed.

10. Task. Prepare and submit monthly reports as required.

    Results. All reports for the first year of the project have been submitted on time. These include monthly reports, as well as quarterly reports.

Deliverable status: Completed.

Other Project Activities

In addition to the project tasks, the following other project tasks are reported:

- The project kick-off meeting was held on August 29, 2008.
- Several students have been involved in the project to date. These include Kyle Crawford (Ph.D. student), Sushmita Susheelendra (M.S. student), Joshua Cuneo (M.S. student) and Joel Feyereisen (B.S. student).
- A project site visit was held to review the project status on June 10, 2009.
- A number of collaborative relationships were established that will help the project. These relationships are with:
  - Researchers involved in creating drama managers in interactive dramas,
  - Researchers involved in using ABL for behavioral modeling, and
  - Another project that will use organizational simulation as part of its efforts to understand risk in the global delivery system of the F-35 fighter.

Project Preparedness and Plans for Year 2

The activities and results from the first year of this project have prepared project personnel for success in addressing the tasks for the project's second year. In particular, such preparations are as follows.

1. Task. Refine/enhance designs and implementations of first generation libraries designed in year one.

   Preparations/plans. Clearly, the first generation class libraries developed in year one provide preparation for this task. Our road map for enhancing the libraries consists of the following.

   Planned enhancements to organizational component libraries:
   - Skills and skill levels
   - Additional relationships
     - Incentives and information
     - Contractual
     - Communication level
     - Skill-set affinity
     - Location
   - Additional organizational artifacts
     - Chart of accounts
     - Decision support systems
   - Eco-systems
     - Direct elements represented as agent-based models
     - Indirect elements represented as system dynamics models
   - Outcomes and value
     - Enhanced with more detail and with analytic support classes

Planned enhancements to role model libraries:

- Wider set of roles
- Social roles
  - Gatekeeper
  - Bridge
  - Hub
- Methods linking roles to actor behavior characteristics via parameterization
- Methods linking evolving social network characteristics to actor social roles

Planned enhancements to behavior and social phenomena libraries:

- Additional behaviors
  - Invocation of and interaction with decision support systems
  - Enhancements of year one behaviors
  - Parameterization of year one behaviors with skill, role, relationship and personality
- Joint character behaviors via ABL constructs
- Investigation of utilizing fuzzy logic theory in the behavioral representations

The timeline for this task is as follows:

- Initiate design/implementation for library enhancements using a spiral approach (start in August 2009)
- Address library export issue (start in October 2009)
- Develop relational model for abstractions to support database integration for improved data management (start in January 2010)

2. Task. Implement organizational story drama manager.

   Preparations/plans. The requirements, functionality and design of the drama manager in year one set the stage for successfully implementing the drama manager. That said, this is a challenging, but doable task. The concept of drama management is new even to the field of gaming and artificial intelligence and thus is not well-defined. Translating this concept to organizational simulation, however, will yield a novel and valuable tool for studying and designing organizations.

   The timeline for this task is as follows:

   - Continue implementation using a spiral approach (start in August 2009)
   - Test and debug implementation (start in January 2010)
   - Apply drama manager to case study (start in March 2010)
   - Investigate development of capability for user-in-the-loop support by the drama manager (start in May 2010)

3. Task. Design and implement software that translates organization and role model representations into computational forms suitable for one or more off-the-shelf simulation engines.

Preparations/plans. Since the AnyLogic product provides an integration platform for all three simulation paradigms used in this project, and since it provides capability to integrate the project's Java class libraries directly with its API, this task is largely accomplished already.

4. Task. Design and implement animation tools that enable groups to interact with the organizational simulation to design and evaluate alternate organizations.

   Preparations/plans. This task is not directly addressed by any of the year one tasks in terms of preparation. To some extent, it will be facilitated by the graphical IDE provided by AnyLogic. Additional functionality will need to be developed, however, to address this task successfully.

   The timeline for this task is as follows:
   - Specify requirements for tools (start in August 2009)
   - Develop design and select technologies for tools (start in November 2009)
   - Implement tools using a spiral approach (start in February 2009)

5. Task. Develop case study models based on HSI case study defined in year one as part of final verification and validation.

   Preparations/plans. The selection of the Predator acquisition case study, as well as development of first-generation class libraries, provides a solid basis for this activity. There has been general agreement that this case study will provide a valuable study for the simulation capability being developed by the project. We understand that there is the possibility of working with someone involved in Predator development issues to provide further data/details for the case study models.

   The timeline for this task is as follows:
   - Initiate process to work with personnel involved in Predator development (start in August 2009)
   - Define scope and content of case study (start in August 2009)
   - Initiate model development via spiral process (start in November 2009)
   - Validate model results (start in May 2010)

6. Task. Present findings at a technical conference.

   Preparations/plans. The work done in the first year and in the first part of the second year with respect to human behavior modeling, drama management and/or the case study will provide good material for a technical presentation at a conference in year two of the project. The following conferences are under consideration:
   - Industrial Engineering Research Conference (the pre-eminent conference of the industrial engineering research community)
   - INFORMS Annual Meeting (the pre-eminent conference of the operations research and management science community)

- Winter Simulation Conference (the pre-eminent conference of the computer simulation research community)

A decision for a specific technical conference will be made in October 2009.

7. Task. Prepare and submit monthly reports as required.

   Preparations/plans. This task will be handled similarly to the analogous task in year one. We do not anticipate any issues with timely filing of reports.

8. Task. Prepare and submit final report.

   Preparations/plans. Similar to the filing of monthly and quarterly reports, we do not anticipate any issues with a timely filing of the final report for the project.

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Appendix A. Software packages reviewed

- AnyLogic
- ARENA Basic
- ARENA Pro
- ARENA Enterprise
- AutoMod
- DSOL
- ExtendSim
- FlexSim
- MASON
- MATLAB/Simulink
- MicroSaint Sharp/IPME
- NetLogo
- PowerSim
- ProModel
- Repast
- SimLib
- Stella/iThink
- Swarm
- Vensim

Appendix B. Presentation at 2009 Industrial Engineering Research Conference

Abstract. The military acquisition enterprise is responsible for conceptualizing, designing, developing, deploying and supporting systems for the U.S. military (e.g., airplanes, ships, unmanned aerial systems, missile systems, etc.). Despite numerous attempts at reform, systems typically are behind schedule and over-budget. One difficulty is an organizational effect – the multi-stakeholder nature of the acquisition enterprise (e.g., military services, defense contractors, Congress and the executive branch, taxpayers). This paper discusses development of an organizational simulation framework to serve as a design aid for acquisition policies and processes that operate in this organizational context. In particular, the focus is on where human-system integration issues should be addressed in the acquisition process. The framework integrates discrete-event simulation, agent-based simulation and system dynamics, and it features a support library of organizational constructs. Implementation of this framework via mapping to existing simulation engines is discussed, and application to the acquisition case study is presented.